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# CONTROL OF CARBON DIOXIDE CONTENT IN AN AIR-SUPPORTED PLASTIC GREENHOUSE 1/

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Many investigators have shown that under certain conditions increasing the carbon dioxide concentration of the atmosphere to which a plant is exposed will increase the rate of photosynthesis. As early as 1905, Blackman 3/ set forth a theory that he called "optima and limiting factors." This theory stated that when a process such as photosynthesis is controlled by a number of separate factors the rate of the process is limited by the level of the minimum factor. The carbon dioxide concentration may be the minimum factor and limit the rate of photosynthesis; thereby plant production is limited.

The normal atmospheric concentration of carbon dioxide is generally considered to be 300 parts per million (p.p.m.), but it varies with climatic conditions. Goldsberry and Holley 4/ reported that during winter months, when a greenhouse was not ventilated, the carbon dioxide content was reduced to 200 p.p.m. during sunlight hours. They also stated that carbon dioxide may be a more limiting factor to plant growth than low light levels under greenhouse conditions.

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1/ Scientific Paper 2372, Washington Agricultural Experiment Stations. Work was conducted under Project 1632.

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3/ Blackman, F. F. Optima and limiting factors. Ann. Bot. 19: 281-295. 1905.

4/ Goldsberry, K. L. and Holley, W. D. Carbon dioxide in the greenhouse atmosphere. Colo. Flower Growers Assoc., Inc., Bul. 119. 1961.

Went [5] stated that "the rate of carbon dioxide uptake depends primarily on the concentration gradient of carbon dioxide from the atmosphere to the leaf." The gradient can be raised by increasing the concentration of the carbon dioxide in the air or increasing the rate of air flow over the surface of the leaf.

Some factors that have retarded the use of supplemental carbon dioxide in greenhouses are the cost of the gas, leakage of the gas from the buildings, unavailability of equipment for measuring and controlling the carbon dioxide concentration, and the lack of adequate air recirculation systems in the greenhouses. Air movement is necessary to insure uniform distribution of the carbon dioxide in the greenhouse and to increase the efficiency of the use of available carbon dioxide by the plants. However, ventilation must be kept to a minimum in order to minimize the cost of $CO_2$. Research on plastic air-supported greenhouses by Matson, Jordin, and Sobek [6] indicated that their use might minimize carbon dioxide losses and at the same time provide an adequate air recirculation system.

This paper reports on phases of a project jointly conducted by the Agricultural Engineering Research Division of the Agricultural Research Service, the Departments of Agricultural Engineering and Horticulture of the Washington Agricultural Experiment Stations, and the Washington Farm Electrification Committee. The objectives of the project were to study the engineering problems encountered in controlling the carbon dioxide concentration in an air-supported plastic greenhouse and to gather information on the effects of different concentrations of carbon dioxide on greenhouse crops. The details of the greenhouse construction and the design and testing of the instrumentation system for controlling the carbon dioxide concentration are discussed. Plant data were taken for two winter growing seasons, but these are not reported in detail in this paper. Significant increases in the yield of carnations, tomatoes, lettuce, and radishes grown in a carbon dioxide enriched atmosphere were observed. Bean, pea, and stock plants grown under like conditions increased in growth rate and in total dry weight produced.

## Greenhouse Construction

Three identical 14- by 23-foot air-supported plastic greenhouses were constructed. One served as a control (no carbon dioxide added). In the other two, the carbon dioxide concentration was controlled automatically. The control instruments were housed in a small instrument building near the north end of the greenhouses. The sampling tubes and carbon dioxide induction tubes were placed in underground concrete conduits connecting the instrument house to each greenhouse. The completed greenhouses and instrument building are shown in figure 1.

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[5] Went, F. W. The experimental control of plant growth. Chronicle Botanic Co., Waltham, Mass. 1957.

[6] Matson, W. E., Jordin, D., and Sobek, I. G. Air supported plastic greenhouse. 1960 Progress Report, Washington Farm Electrification Committee and Dept. of Agric. Engineering of Washington State Univ., Pullman, Wash. 1960.

Figure 1.--Air-supported plastic greenhouses in which the carbon dioxide concentration is controlled automatically.

Figure 2 shows the construction details of each greenhouse. A 1/2-hp., two-speed centrifugal blower provided air for support and ventilation of each greenhouse. Ventilation was controlled by adjusting the air-intake louvers, by changing the blower speed, or both. To provide the necessary air movement

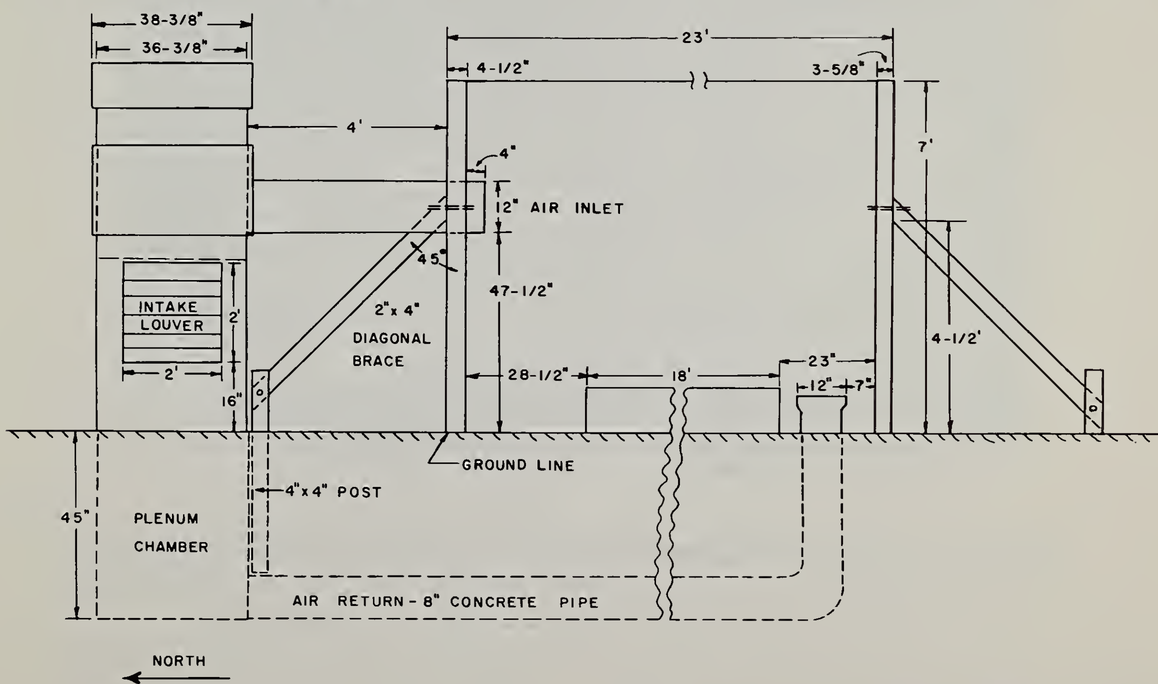


Figure 2.--Construction details of plastic greenhouse.

and still minimize carbon dioxide losses, an air recirculation system consisting of seven 8-inch-diameter concrete pipes were buried 40 inches beneath the ground line spaced 2 feet on centers horizontally.

Each greenhouse was covered with two layers of 6-mil clear polyethylene film with an airspace between. The airspace of approximately 2 inches was established between the layers by maintaining a small pressure differential with a 1/60-hp. blower. The end panels were wood frame construction. The north panel was covered with plywood and the south panel was covered with clear polyethylene. Additional details on the design and construction of this type of building have been reported by Matson, Jordin, and Sobek. 7/

## Carbon Dioxide Control System

The carbon dioxide control system was initially designed to sample air from each of the three greenhouses and the outside atmosphere, record the carbon dioxide content from each of these locations, and control the carbon dioxide concentration in two of the greenhouses. Since the initial design, the capability of the system has been increased so that the concentration in three greenhouses can be controlled. The system consisted of a station selector, infrared gas analyzer, sampling pump, strip-chart recorder controller, carbon dioxide induction valve, and a source of carbon dioxide. Gasmeters in each greenhouse were used to measure the amount of carbon dioxide used. Figure 3 shows a line diagram of the carbon dioxide control system and figure 4 shows the details of one channel of the system. The instruments are pictured in figure 5.

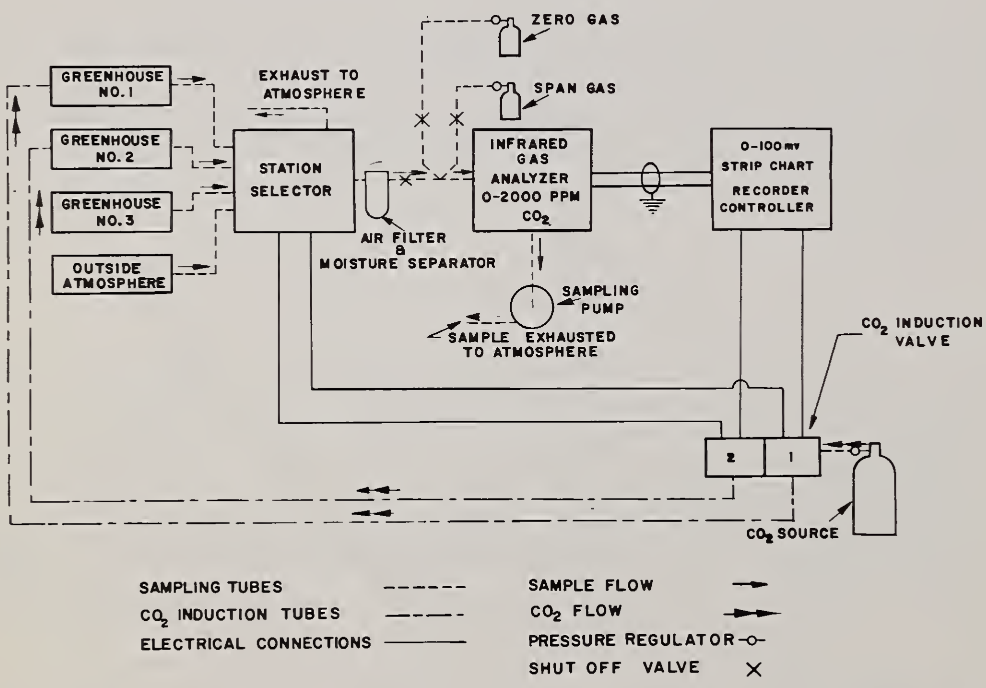


Figure 3.--Line diagram of carbon dioxide control system.

7/ See footnote 6 on page 2.

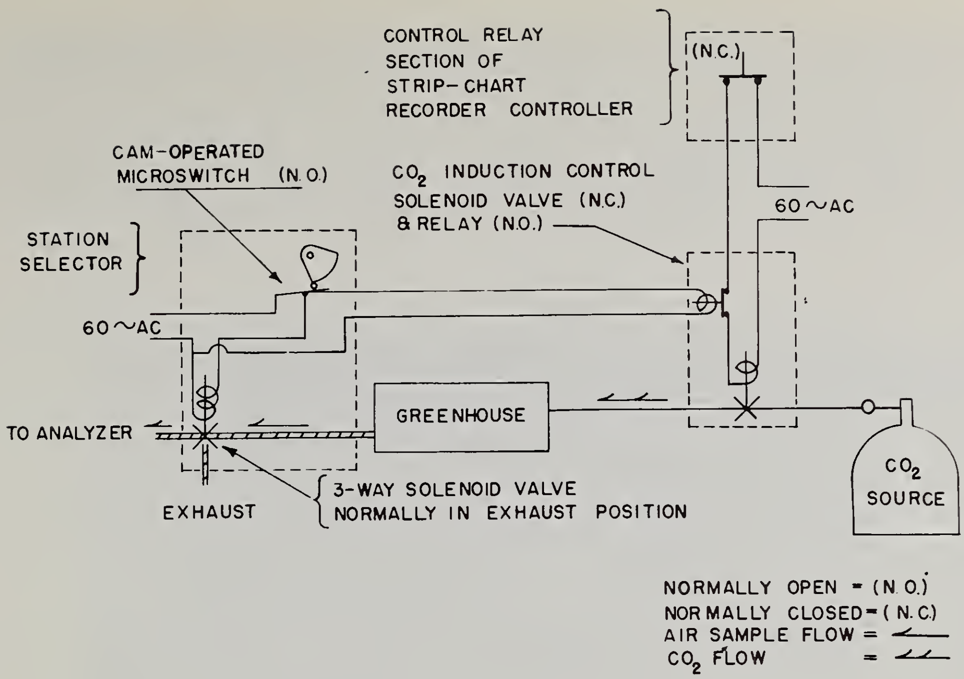


Figure 4.--Details of one channel of the carbon dioxide control system.

Figure 5.--Carbon dioxide control instruments. Shown, from left to right, are the station selector (constructed by project personnel), carbon dioxide induction valve (constructed by project personnel), recorder controller (Honeywell Electronik 17, 0 - 100 mv), and infrared gas analyzer (Mine Safety Appliances, Lira Model 300, 0 - 2000 ppm carbon dioxide in air).

The station selector (figure 6) consisted of a set of cam-operated microswitches. These switches controlled solenoid valves in the sampling tubes leading from each station. The length of time that each station was monitored was governed by the speed of the cam-drive motor and by the length of the cam lobes used. The number of stations that can be sampled can be increased by adding sets of solenoid valves and microswitches.

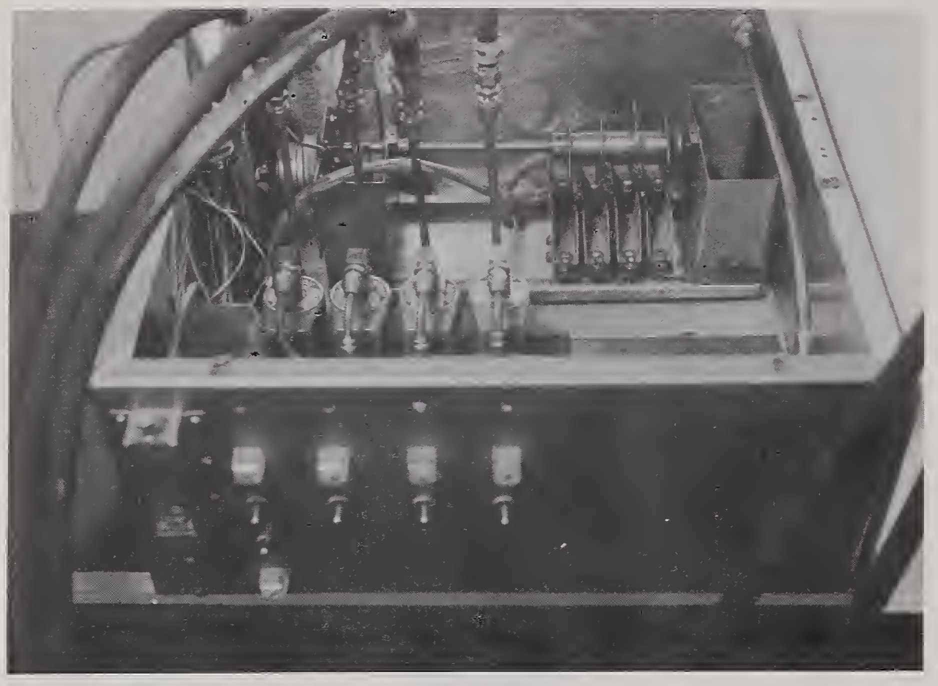

Figure 6.--Station selector.

The carbon dioxide induction system consisted of a hand-operated flow valve in parallel with a controller-operated solenoid valve for each greenhouse to which carbon dioxide was to be added. The hand-operated valve was set to bleed carbon dioxide into the greenhouse continuously at a rate slightly less than the rate at which it was being depleted from the greenhouse. The controller-operated solenoid valve opened to admit carbon dioxide to make up for the decrease in concentration that occurred while other locations were being monitored. The station selector and the solenoid section of the carbon dioxide induction valves were electrically connected so that carbon dioxide was added only during the interval that a greenhouse was being monitored.

A typical cycle of operation of the control system is as follows (figure 4). A cam in the station selector closes a microswitch. This opens the solenoid valve in the station selector and closes the relay in the carbon dioxide induction valve. A sample from this particular station is pulled through the analyzer and its carbon dioxide content determined. A millivolt signal, which is proportional to the carbon dioxide concentration, is sent from the analyzer to the recorder controller where it is recorded and also may activate the normally closed relay in the controller section of this instrument. If this signal indicates that the carbon dioxide level is at or above the control point, no carbon dioxide is added. If the carbon dioxide level is below the control point, the relay in the controller remains closed, which allows the carbon dioxide induction valve to open and carbon dioxide to enter the greenhouse.

A typical section of the chart recording carbon dioxide concentrations is shown in figure 7. Points A, B, C, and D are readings in the control greenhouse (no carbon dioxide added), the greenhouse controlled at 900 p.p.m., the greenhouse controlled at 1,800 p.p.m., and in the outside atmosphere, respectively. This particular recording was made on a bright clear day when photosynthesis was at a high rate. For this reason, the carbon dioxide concentration in the control house was less than that of the outside atmosphere.

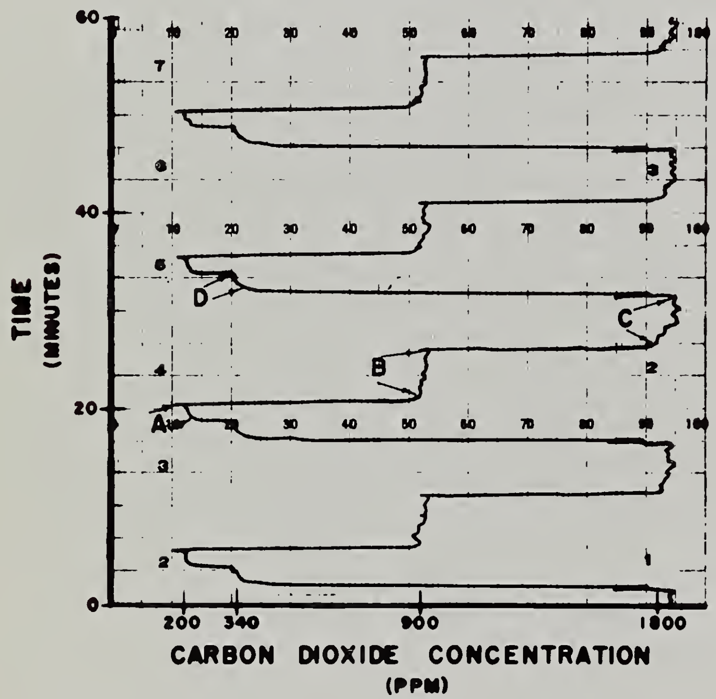


Figure 7.--Section of chart record showing carbon dioxide concentrations. Points A, B, C, and D are the control house, 900 p.p.m. house, 1,800 p.p.m. house and outside atmosphere, respectively.

Results of previous work [8] had indicated the necessity of proper air movement to insure uniform carbon dioxide distribution and efficient use of the available carbon dioxide by the plants. Tests were conducted to determine the carbon dioxide distribution in the greenhouses at various concentrations and stages of plant growth. A portable multiple-sampling system that allowed consecutive sampling from 12 locations within each greenhouse was constructed

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[8] See footnote 5 on page 2.

and used for these tests. Excellent uniformity of concentration was found; the maximum deviation was about 3 percent in a greenhouse containing tomato plants in full foliage.

## Discussion

The control system that is described in this paper was developed as a research unit to be used to study the problems encountered in controlling carbon dioxide in greenhouses and to gather information on the effects of various concentrations of carbon dioxide on greenhouse crops. The system worked very well in the small 14- by 23-foot air-supported greenhouses in which it was used. It has not been tested in larger greenhouses or in greenhouses of standard glass construction, but it probably could be used in larger greenhouses if proper air movement was provided. No work was done to determine the minimum rate of air movement required to insure uniform carbon dioxide distribution within the greenhouses. For these tests, a rate equivalent to approximately 50 air changes per hour was used and found to provide excellent distribution. During the winter months this entire amount of air was recirculated.

This system probably could readily control the concentration in as many as six greenhouses. With six greenhouses operating under the system, each could be monitored for a 5-minute period out of each half hour. This should provide good control. This system would provide essentially automatic control of each greenhouse at any selected carbon dioxide concentration from atmospheric to 2,000 p.p.m. However, a daily check of each hand-valve setting would be required as plants grew and required more carbon dioxide for photosynthesis.

A careful study of the economics involved should be made before this control system is used. Some factors that should be considered are the benefits to be obtained by adding carbon dioxide, the cost of the carbon dioxide, and the initial cost of the control system. The source of the supplemental carbon dioxide and the amount of ventilation required to maintain the desired greenhouse temperature affect the cost. A point can be reached where it is not economically feasible to add carbon dioxide because of the ventilation required for temperature control. Dry ice was used as the source of carbon dioxide for these tests. The dry ice was placed in high pressure tanks (dry ice converters) and the carbon dioxide gas taken out through a pressure regulating valve for introduction into the greenhouses. Other sources of carbon dioxide need to be evaluated.

## Summary

A control system for measuring, recording, and controlling the carbon dioxide concentration in an air-supported plastic greenhouse has been developed. The system consists of an infrared gas analyzer, a cam-actuated station selector, and a carbon dioxide induction valve. The system can control the carbon dioxide concentration in as many as six greenhouses at any desired level from atmospheric up to 2,000 p.p.m. The controller has proved very successful in 2 years' operation in 14- by 23-foot air-supported plastic greenhouses.